DTU Library

Estimating escapement of fish and invertebrates in a Danish anchor seine

Noack, Thomas; Madsen, Niels; Mieske, Bernd; Frandsen, Rikke; Wieland, Kai; Krag, Ludvig Ahm

Published in:
ICES Journal of Marine Science

Link to article, DOI:
10.1093/icesjms/fsx066

Publication date:
2017

Document Version
Peer reviewed version

Citation (APA):
Noack, T., Madsen, N., Mieske, B., Frandsen, R., Wieland, K., & Krag, L. A. (2017). Estimating escapement of fish and invertebrates in a Danish anchor seine. *ICES Journal of Marine Science*, *74*(9), 2480-2488. https://doi.org/10.1093/icesjms/fsx066

Estimating escapement of fish and invertebrates in a Danish anchor seine

Thomas Noack[1*], Niels Madsen[1,2], Bernd Mieske[3], Rikke P. Frandsen[1], Kai Wieland[1], Ludvig A. Krag[1]

[1]Technical University of Denmark, National Institute of Aquatic Resources, North Sea Science Park, PO Box 101, DK-9850 Hirtshals, Denmark

[2]Section of Biology and Environmental Science, Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7, 9220 Aalborg, Denmark

[3]Thünen-Institute of Baltic Sea Fisheries, Alter Hafen Süd 2, 18069 Rostock, Germany

[*]Corresponding author: tel: +45 35 88 32 60; fax: +45 35 88 32 60; email: thno@aqua.dtu.dk

Abstract

The codend is generally presumed to be the place where the main selectivity of fish occurs in towed fishing gears, but other parts of the net have been found to contribute to the selectivity process of several invertebrate species. This means that conventional selectivity or survival studies may ignore the selectivity of net parts other than the codend for certain species. By attaching 12 small meshed collecting bags to different parts of a Danish anchor seine net and conducting normal commercial fishing activities, this study showed that there is a substantial escapement of fish and (especially) invertebrates from the forward parts of the seine net. For seven species of demersal fish, most fish escaped through the lower panel close to the codend. All invertebrate species were found in higher numbers in the collecting bags than in the codend where many organisms escaped in the lower panel of the wings or the belly. Mean levels of visible damage ranged from 1.00 to 3.25 for collected invertebrates and were similar for all gear parts. Common starfish (*Asterias rubens*), however, showed highest damage in the extension part of the net.

Keywords: Damage index, Ecosystem effects, Sea bed impacts, Selectivity, Skagerrak, Unaccounted mortality

Introduction

The codend is the part of towed fishing gears where the catch is collected and where the main selection of fish occurs (Wileman *et al.*, 1996). Therefore, most studies on towed fishing gears, e.g., selectivity studies on trawls (e.g., Reeves *et al.*, 1992; Graham *et al.*, 2004; Frandsen *et al.*, 2010) or Danish anchor seines (e.g., Herrmann *et al.*, 2016; Noack *et al.*, 2017), or survival studies (e.g., Bergmann and Moore, 2001; Uhlmann *et al.*, 2016), focused on the individuals in or escaping from the codend. Previous studies on the selectivity of commercially valuable crustaceans in different types of trawls, however, found that a substantial part of the selection of Norway lobster (*Nephrops norvegicus*; Hillis and Earley, 1982), brown shrimp (*Crangon crangon*; Polet, 2000) and Antarctic krill (Euphausia superba; Krag *et al.*, 2014a) takes place in the forward parts of a trawl net. It may be expected that other invertebrates (Wileman *et al.*, 1996) and possibly some fish species show similar patterns in towed fishing gears. Such trawl-body selectivity cannot be seen and is not considered in studies that are limited to the codend. Therefore, the magnitude of such escape and the potential damage to individuals caused by interactions with the fishing gear remain unaccounted for in standard selectivity and survival studies.

There is an increased focus on expanding the understanding of how various types of fishing affect the marine ecosystem during their deployment (Fulton *et al.*, 2014). This highlights the need to gather information on different fishing methods, including Danish anchor seining which is considered to be a fuel-efficient fishing method (Thrane, 2004; Suuronen *et al.*, 2012; Walsh and Winger, 2011) with low environmental impacts compared to other demersal fishing gears (Suuronen *et al.*, 2012; Eigaard *et al.*, 2016; Walsh and Winger, 2011) that delivers high quality catches (Dreyer *et al.*, 2008; Suuronen *et al.*, 2012; Walsh and Winger, 2011). One example of integrating the ecosystem effects of different fishing gears into management strategies is the current EU Common Fisheries Policy (Zhou *et al.*, 2010) which aims at assessing and reducing potential negative impacts from fishing gears on the marine habitat. An assessment of unaccounted selectivity is therefore important, particularly if these unobserved interactions can lead to unaccounted mortality.

The escape of animals from a Danish seine may vary in numbers, sizes and between species in the different gear parts, e.g., because the fishing process is partly asymmetrical and the numbers of animals entering each side of the gear are likely to be different (Wileman *et al.*, 1996). To account for this in this study, the net of a Danish seine was divided into different parts which were strategically covered with small mesh bags. Previous studies on trawls demonstrated successfully that small mesh bags or pocket meshes can be used to estimate escapement of fish and invertebrates from gear parts other than the codend (Hillis and Earley, 1982; Nakashima, 1990; Dremiere *et al.*, 1999; Williams *et al.*, 2011; Suuronen *et al.*, 1997). This setup was used under the commercial conditions of Danish seining in Danish waters to collect escaping fish and invertebrates throughout the gear. To quantify the effects of net interaction and escape on the collected animals, damage was assessed for all caught invertebrates. This served as a measure to indicate potential mortality and to compare selectivity and damage in the different parts of the seine net.

Material and Methods

Study site and experimental setup

Experimental fishing was carried out with the commercial Danish seiner HG 35 *Vendelbo* (length overall: 15.47 m, engine power: 91 kW) in August and September 2014. All hauls were carried out off the coast of Denmark in Skagerrak (ICES area IIIa; Figure 1). As commercial Danish seining is not only conducted on sandy flatfish areas close to the coast (e.g., for plaice *Pleuronectes platessa*), but also on deeper whitefish grounds (e.g., for haddock *Melanogrammus aeglefinus* and cod *Gadus morhua*), this study was conducted in both area types (Figure 1).

Twelve small mesh collecting bags with a nominal mesh size of 45 mm (Figure 2) were attached to different parts of the vessel´s seine net (for vessel and gear specifications, see Noack *et al.* (2017)). Each collecting bag was 4.8 m long (stretched) and covered ~ 0.5 m^2 of the seine netting (55 - 121 meshes, depending on mesh size and mesh configuration of the specific net part). As the global geometry of a Danish seine changes considerably during the fishing process, we expected the netting characteristics of the different net parts to do the same. Due to the size of the seine net, such effects could not be experimentally tested in a flume tank. The collecting bags were therefore mounted with the aim of covering the same area of netting without distorting the seine during any stages of the fishing process. Collecting bags that were attached to the wings (bags 1-8) were not modified with weight or floats as a sufficient opening of those was expected to be achieved by the angle of the wings in relation to the towing direction. The collecting bags that were attached to the belly and the extension part of the net were expected to potentially mask the netting of the seine part they covered. To account for this, the two collecting bags in the upper panel of belly and extension (bags 9 and 11, Figure 2C) were equipped with four floats and a lead rope was attached to the two collecting bags in the lower panel (bags 10 and 12, Figure 2D) to prevent masking. To assess their performance, two underwater video cameras (GoPro Hero 3^+) without artificial light were attached close to collecting bag 9 in the upper panel and collecting bag 10 in the lower panel during hauls 1 and 7.

Data collection and sampling strategy

Fishing time, anchor depth and depth at the position where the net was deployed were recorded as well as sea state following the protocol of Wileman *et al.* (1996). Vessel movement during the fishing process was tracked for each haul, using a GPS-logger (Canmore G-PORTER GP-102+). After each haul, fish and invertebrates were separated, fish were measured to the nearest cm below and individual weights were estimated using length weight relationships (Coull *et al.*, 1989). All invertebrates were frozen until treated further on land where they were identified, counted, length measured to nearest mm and weight measured to nearest mg. Length measurements differed from species to species, based on their body shape (see Table 1 for details). Additionally, a damage index based on Veale *et al.* (2001) was applied to each individual, whereby levels depended on individual species characteristics (Table 1). The lowest level of damage for sessile organisms (Porifera and Anthozoa) was set to “Level 3”, because detaching sessile organisms from their substrate was also considered a damage which reduced their chance of surviving the interaction with the fishing gear. Due to large codend catches, catches of plaice were subsampled within the first three hauls (range of subsampling factor: 0.07 – 0.70) following the guidelines of Gerritsen and McGrath (2007).

Data analysis

After providing individual haul information, hauls from the two area types were pooled to provide a combined picture for the areas where Danish seiners fish commercially. The seven hauls conducted did not allow for separate analyses between the two areas as numbers of individuals caught in the collecting bags were relatively low. Numbers of individuals in the collecting bags were raised to a value indicating how many individuals passed through the netting of the respective part of the gear using a raising factor (number of meshes covered by bag/number of meshes in gear part) ranging from 0.01 to 0.07. Graphical catch distributions of fish and invertebrates were made based on raised values showing both absolute and relative catch numbers in the collecting bags. Besides numbers of individuals, average sizes (mean ± standard deviation) of the animals observed in the collecting bags are given. Due to low numbers of individuals per single bag, values were pooled for the “upper collecting bags” (collecting bags 1, 3, 5, 7, 9, 11) and the “lower collecting bags” (collecting bags 2, 4, 6, 8, 10, 12). Hermit crabs (*Pagurus* spp.), which lost their shell, as well as sea stars without any arms were excluded from this part of the analysis as a proper length measurement was not possible for those. A one-way analysis of variance (ANOVA) with gear part as fixed factor followed by a Tukey-HSD test was used to test for significant differences between mean length of the caught organisms in the different gear parts (significance level $\alpha \leq 0.05$).

Finally, visual damages were registered and the damage indices of the caught invertebrates were compared between the gear parts. This part was restricted to species observed in at least two different gear parts. A one-way analysis of variance (ANOVA) with gear part as fixed factor followed by a Tukey-HSD test was used for each species to test for significant differences between damage levels in the different gear parts (significance level $\alpha \leq 0.05$).

All analyses were done using R Statistical Software (Core Team, 2012).

Results

Haul overview

Seven valid hauls with durations ranging from 131 to 180 min were conducted (Table 2). The hauls were carried out in depths between 12.8 and 73.2 m and covered an area ranging from 2.6 to 3.5 km^2. Codend catches ranged from 94 to 2172 kg per haul. The sum of catches in the collecting bags ranged from 0.5 to 2.4 kg per haul. Inspection of underwater recordings showed that the floats attached to the collecting bags in the upper panel and lead lines attached to the collecting bags in the lower panel worked as intended as the bags did not mask the meshes of the seine net (Figure 3).

Catches of fish

A higher diversity of fish species was observed in the codend than in the collecting bags (bags: 14 species, codend: 21 species, total: 26 species) and nine species were observed in both codend and at least one of the collecting bags (cod, dab *Limanda limanda*, flathead grey mullet *Mugil cephalus*, grey gurnard *Eutrigla gurnardus*, lemon sole *Microstomus kitt*, plaice, red gurnard *Chelidonichthys cuculus*, sole *Solea solea* and whiting *Merlangius merlangus* (Table 3)). For all of them, except for plaice and red gurnard, the number of fish in the codend was lower than the sum of the raised numbers in the collecting bags (Table 3). The number of individuals escaping through meshes in the wings was very low but increased towards the codend (Table 3). As also shown in Figure 4, the number of individuals was considerably higher in bags from the lower panel. Only herring (*Clupea harengus*), sprat (*Sprattus*

sprattus) and whiting escaped to a large extent through the upper panel in the aft part of the seine net. Differences in the horizontal plane were minor (Table 3, Figure 4). In the cases of dab and plaice, individuals in the upper bags were significantly larger than in the lower bags (Table 3).

Catches of invertebrates

Twelve of twenty invertebrate species caught were found in the collecting bags and 15 species were found in the codend (Table 3). For species that were observed in both codend and at least one collecting bag (common starfish *Asterias rubens*, common whelk *Buccinum undatum*, hermit crabs, red whelk *Neptunea antiqua*, sand star *Astropecten irregularis*, sandy swimming crab *Liocarcinus depurator*, sponges *Porifera* spp.), the sum of raised numbers from the collecting bags was higher than the number of individuals observed in the codend (Table 4). Numbers in the collecting bags of the lower wings and the lower aft part of the gear were similar, but only two organisms were observed in the bags of the upper panel (Table 4). More individuals were found in the collecting bags of the portside wing than in bags of the starboard wing (Table 4, Figure 5). For both species that were observed in lower and upper bags (brown shrimp, common starfish), average length was significantly higher for individuals in the upper bags (Table 4).

Damage index

Means of the estimated levels of damage ranged from 1.00 to 3.25, but were generally low for the inspected species (Table 5). Values of 2.00 were exceeded only by common starfish in the extension, by sand stars in the codend and by sponges in the inner wings and the codend (Table 5). Comparing damage indices of invertebrates was limited by the issue of unequally distributed species, allowing the comparison for only nine species (brown shrimp, common starfish, common whelk, hermit crab, purple heart sea urchin *Spatangus purpureus*, red whelk, sand star, sandy swimming crab, sponges; Table 5). Differences between the gear parts were small and significant differences were only found for common starfish having significantly higher damage levels in the extension bags than in outer wing bags and belly bags (Table 5).

Discussion

The results of this study clearly showed that fish and especially invertebrates interact with, and escape from, most parts of a commercial Danish anchor seine during the fishing operation. The majority of invertebrates were caught in the collecting bags mounted to the lower panel of the seine net, whereas the relatively few caught fish were primarily found in the collecting bags close to the codend. The part of the selection in gear parts other than the codend is substantial and is currently not accounted for in conventional selectivity studies that are based on codend catches. Paired or alternate haul techniques (Wileman *et al.*, 1996) could potentially show this effect, but would not be able to describe in which part of the seine net the selectivity occurred.

As has also been shown by previous studies (Hillis and Earley, 1982; Dremiere *et al.*, 1999; Williams *et al.*, 2011; Suuronen *et al.*, 1997; Nakashima, 1990), collecting bags provide a suitable option to investigate escapement of animals from gear parts of mobile fishing gears where conventional techniques like covers are not possible to be used. However, it is important to treat the estimated numbers of escapees with care. Although the collecting bags were distributed over the entire commercial seine net, to indicate each parts' selectivity, they only covered a small fraction (3-15%) of the part they were mounted to. In addition, there were generally low amounts of individuals in the study area, which probably explains the relatively low numbers in the collecting bags. Furthermore, our resulting pooling of the data may have masked any potential area effect. More or larger small meshed collecting bags on the seine net were considered to increase the risk of affecting the commercial operation of the seine net due to extra drag. As twine characteristics, mesh sizes, mesh openings and thus the potential selectivity vary between different parts in the seine net, so does the catch in the different collection bags. The catches in the collecting bags might also be affected by considerable changes in the entire net geometry during the fishing process, starting with a loose net in the beginning that goes over a period of being overspread (high horizontal opening, low vertical opening) to a completely closed phase in the final stages of the retrieval process. Based on the conducted underwater observations, this did, however, not seem to affect the operation of the observed collecting bags.

The majority of fish species escaped in the aft part of the gear, which has also been observed for capelin in midwater trawls (Nakashima, 1990) and other species in bottom trawls (Dremiere *et al.*, 1999). Demersal species escaped preferentially through the lower panel, where pelagic species like herring and sprat escaped solely through meshes in the upper panel in the aft part of the gear. Preferences of pelagic fish to escape upwards were also made by a study that investigated escapement in bottom trawls (Dremiere *et al.*, 1999) and a study that described the behavior of herring in relation to midwater trawls (Suuronen *et al.*, 1997). Such species specific behavioral differences can be used to improve the seine net's species or size selectivity as demonstrated for trawls (Thomsen, 1993; Krag *et al.*, 2014b; Krag *et al.*, 2015).

Contrary to fish, invertebrates have limited motility. Where fish swim and actively orientate in relation to the surrounding netting to avoid contact with it (Glass *et al.*, 1993; Glass and Wardle, 1995), invertebrates are expected to roll more passively along the lower netting resulting in multiple contacts with the meshes from the net mouth and back towards the codend. The catches of invertebrates in the collecting bags indicated that most invertebrates escaped through the netting in the lower forward sections of the seine net and that only a small proportion of the invertebrates that entered the seine net ended up in the codend. High numbers of invertebrates escaping from gear parts other than the codend were observed for bottom trawls (Hillis and Earley, 1982; Dremiere *et al.*, 1999). The general selectivity pattern for invertebrates in seine nets and trawls, is therefore different from fish that primarily escape through meshes in the codend (Wileman *et al.*, 1996). This difference between fish and invertebrates can be utilized to reduce catches of unwanted invertebrates without losing fish as fish avoid contact with the forward netting parts (Glass *et al.*, 1993; Glass and Wardle, 1995). In the North Sea, for instance, benthic release panels mounted to the lower netting of beam trawls were found to successfully reduce catches of unwanted invertebrates (Revill and Jennings, 2005).

As the present study showed, codend selectivity does not reflect the entire selectivity process for invertebrates in Danish seines. Quantifying the escape of invertebrates in Danish seines or trawls, as part of a comprehensive description of active gears' interactions with the ecosystem, will require approaches similar to the current approach. The system of collecting bags makes such quantifications possible and further appeared relatively sensitive to pick up small differences between net parts. For instance, higher escape rates of invertebrates in the portside than in the starboard side of the seine net could be indicated. Due to the asymmetrical way the Danish seine is set out and dragged in the early stages of the fishing process (Wileman *et al.*, 1996), these differences were expected. Contrary to invertebrates, this asymmetrical catch tendency was not observed for fish as fish actively avoid the netting (Glass *et al.*, 1993).

The assessment of the invertebrates´ damage indicated relatively low levels of visual damage, which is likely due to their robust exoskeleton or shells. Similar results have been found for trawls (Bergmann *et al.*, 2001). Higher levels of damage in aft parts than in front parts, which were observed for common starfish, indicated that a longer time and distance inside the netting results in more mechanical interaction with the netting. This means that lower damage levels can be expected if such animals could be released earlier in the process. The commercial seine net used in the current study had relative large meshes in the forward sections of the seine net (120 - 160 mm) which presumably resulted in already high numbers of escapees. In smaller mesh designs, it would be expected that the organisms require a higher contact probability with the netting to successfully escape, if physically possible. Such designs, which can be found in the *Nephrops* directed trawl designs (Krag *et al.*, 2008) may result in an increase of mechanical damages due to the increased netting contact and longer towing durations. However, the damage assessment in the current study considered only visible external damages and conclusions of previous studies about relationships of external damages and mortality are inconsistent (Broadhurst *et al.*, 2006). Therefore, the degree of damage cannot be translated directly into mortality rates and future experiments should include survival assessments and evaluate mechanical as well as physiological damage as a proxy for survival. If it is concluded that low survival is the consequence of organisms´ interaction with seines or trawls, then there is a need to develop invertebrate release systems similar to the benthic release panels used in some beam-trawl fisheries (Revill and Jennings, 2005). By applying the findings of the present study, these devices should be implemented into the front part of the gear.

Supplementary material

The following supplementary material is available at ICESJMS online: Supplementary Table S1 which provides a full catch overview of all observed fish species.

Acknowledgement

The authors thank the crew of HG 35 *Vendelbo*, netmaker Ray Godtliebsen, Gert Holst and Reinhardt Jensen and other technicians from DTU Aqua's monitoring section in Hirtshals, being indispensable in preparing, conducting and follow-up work of the sea trials. Comments to content and language by Javed Khan are greatly acknowledged. The study was carried out as a part of the Skånfisk project with financial support of the Ministry of Environment and Food of Denmark.

References

Bergmann, M., Beare, D. J., Moore, P. G. 2001. Damage sustained by epibenthic invertebrates discarded in the Nephrops fishery of the Clyde Sea area, Scotland. Journal of Sea Research, 45: 105-118.

Bergmann, M., Moore, P. G. 2001. Survival of decapod crustaceans discarded in the Nephrops fishery of the Clyde Sea area, Scotland. ICES Journal of Marine Science, 58: 163-171.

Broadhurst, M. K., Suuronen, P., Hulme, A. 2006. Estimating collateral mortality from towed fishing gear. Fish and Fisheries, 7: 180-218.

Coull, K. A., Jermyn, A. S., Newton, A. W., Henderson, G. I., Hall, W. B. 1989. Length/Weight Relationships for 88 species of Fish Encountered in the North East Atlantic. Scottish Fisheries Research Report 43. 81 pp.

Dremiere, P.-Y., Fiorentini, L., Cosimi, G., Leonori, I., Sala, A., Spagnolo, A. 1999. Escapement from the main body of the bottom trawl used for the Mediterranean international trawl survey (MEDITS). Aquatic Living Resources, 12: 207-217.

Dreyer, B. M., Nøstvold, B. H., Midling, K. Ø., Hermansen, Ø. 2008. Capture-basedaquaculture of cod. In: Lovatelli, A., Holthus, P.F. (Eds), Capture-based aquaculture. Global overview. FAO Fisheries Technical Paper No. 508. pp. 183-198.

Eigaard, O. R., Bastardie, F., Breen, M., Dinesen, G. E., Hintzen, N. T., Laffargue, P., Mortensen, L. O., *et al.* 2016. Estimating seabed pressure from demersal trawls, seines, and dredges based on gear design and dimensions. ICES Journal of Marine Science, 73: i27-i43.

Frandsen, R. P., Madsen, N., Krag, L. A. 2010. Selectivity and escapement behaviour of five commercial fishery species in standard square- and diamond-mesh codends. ICES Journal of Marine Science, 67: 1721-1731.

Fulton, E. A., Smith, A. D. M., Smith, D. C., Johnson, P. 2014. An integrated approach is needed for ecosystem based fisheries management: Insights from ecosystem-level management strategy evaluation. PLOS ONE, 9: e84242.

Gerritsen, H. D., McGrath, D. 2007. Precision estimates and suggested sample sizes for length-frequency data. Fishery bulletin, 105: 116-120.

Glass, C. W., Wardle, C. S. 1995. Studies on the use of visual stimuli to control fish escape from codends. II. The effect of a black tunnel on the reaction behaviour of fish in otter trawl codends. Fisheries Research, 23: 165-174.

Glass, C. W., Wardle, C. S., Gosden, S. J. 1993. Behavioural studies of the principles underlying mesh penetration by fish. ICES Marine Science Symposia, 196: 92-97.

Graham, N., O'Neill, F. G., Fryer, R. J., Galbraith, R. D., Myklebust, A. 2004. Selectivity of a 120 mm diamond cod-end and the effect of inserting a rigid grid or a square mesh panel. Fisheries Research, 67: 151-161.

Herrmann, B., Krag, L. A., Feekings, J., Noack, T. 2016. Understanding and predicting size selection in diamond-mesh cod ends for Danish seining: A study based on sea trials and computer simulations. Marine and Coastal Fisheries, 8: 277-291.

Hillis, J., Earley, J. 1982. Selectivity in the N*ephrops* trawl. ICES C. M. 1982/B19: 1-11.

Krag, L. A., Frandsen, R. P., Madsen, N. 2008. Evaluation of a simple means to reduce discard in the Kattegat-Skagerrak Nephrops (*Nephrops norvegicus*) fishery: Commercial testing of different codends and square-mesh panels. Fisheries Research, 91: 175-186.

Krag, L. A., Herrmann, B., Iversen, S. A., Engås, A., Nordrum, S., Krafft, B. A. 2014a. Size selection of Antarctic krill (*Euphausia superba*) in trawls. PLOS ONE, 9: e102168.

Krag, L. A., Herrmann, B., Karlsen, J. D. 2014b. Inferring fish escape behaviour in trawls based on catch comparison data: Model development and evaluation based on data from Skagerrak, Denmark. PLoS ONE, 9: e88819.

Krag, L. A., Herrmann, B., Karlsen, J. D., Mieske, B. 2015. Species selectivity in different sized topless trawl designs: Does size matter? Fisheries Research, 172: 243-249.

Nakashima, B. S. 1990. Escapement from a Diamond IX midwater trawl during acoustic surveys for capelin (*Mallotus villosus*) in the Northwest Atlantic. ICES Journal of Marine Science ICES Journal of Marine Science, 47: 76-82.

Noack, T., Frandsen, R. P., Krag, L. A., Mieske, B., Madsen, N. 2017. Codend selectivity in a commercial Danish anchor seine. Fisheries Research, 186, Part 1: 283-291.

Polet, H. 2000. Codend and whole trawl selectivity of a shrimp beam trawl used in the North Sea. Fisheries Research, 48: 167-183.

Reeves, S. A., Armstrong, D. W., Fryer, R. J., Coull, K. A. 1992. The effects of mesh size, cod-end extension length and cod-end diameter on the selectivity of Scottish trawls and seines. ICES Journal of Marine Science, 49: 279-288.

Revill, A. S., Jennings, S. 2005. The capacity of benthos release panels to reduce the impacts of beam trawls on benthic communities. Fisheries Research, 75: 73-85.

Suuronen, P., Chopin, F., Glass, C., Løkkeborg, S., Matsushita, Y., Queirolo, D., Rihan, D. 2012. Low impact and fuel efficient fishing—Looking beyond the horizon. Fisheries Research, 119-120: 135-146.

Suuronen, P., Lehtonen, E., Wallace, J. 1997. Avoidance and escape behaviour by herring encountering midwater trawls. Fisheries Research, 29: 13-24.

Thomsen, B. 1993. Selective flatfish trawling. ICES Marine Science Symposia, 196: 161-164.

Thrane, M. 2004. Energy consumption in the Danish fishery: Identification of key factors. Journal of Industrial Ecology, 8: 223-239.

Uhlmann, S. S., Theunynck, R., Ampe, B., Desender, M., Soetaert, M., Depestele, J. 2016. Injury, reflex impairment, and survival of beam-trawled flatfish. ICES Journal of Marine Science, 73: 1244-1254.

Veale, L. O., Hill, A. S., Hawkins, S. J., Brand, A. R. 2001. Distribution and damage to the by-catch assemblages of the northern Irish Sea scallop dredge fisheries. Journal of the Marine Biological Association of the United Kingdom, 81: 85-96.

Walsh, S. J., Winger, P. D. 2011. Bottom seining in Canada, 1948-2010: Its development, fisheries and ecosystem impacts. Canadian technical report of fisheries and aquatic sciences No. 2922. 147 pp.

Wileman, D. A., Ferro, R. S. T., Fonteyne, R., Millar, R. B. 1996. Manual of methods of measuring the selectivity of towed fishing gears. ICES Coop. Res. Rep., No. 215. ICES, Copenhagen. 216 pp.

Williams, K., Punt, A. E., Wilson, C. D., Horne, J. K. 2011. Length-selective retention of walleye pollock, *Theragra chalcogramma*, by midwater trawls. ICES Journal of Marine Science, 68: 119-129.

Zhou, S., Smith, A. D. M., Punt, A. E., Richardson, A. J., Gibbs, M., Fulton, E. A., Pascoe, S., *et al.* 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. Proceedings of the National Academy of Sciences, 107: 9485-9489.

Figures

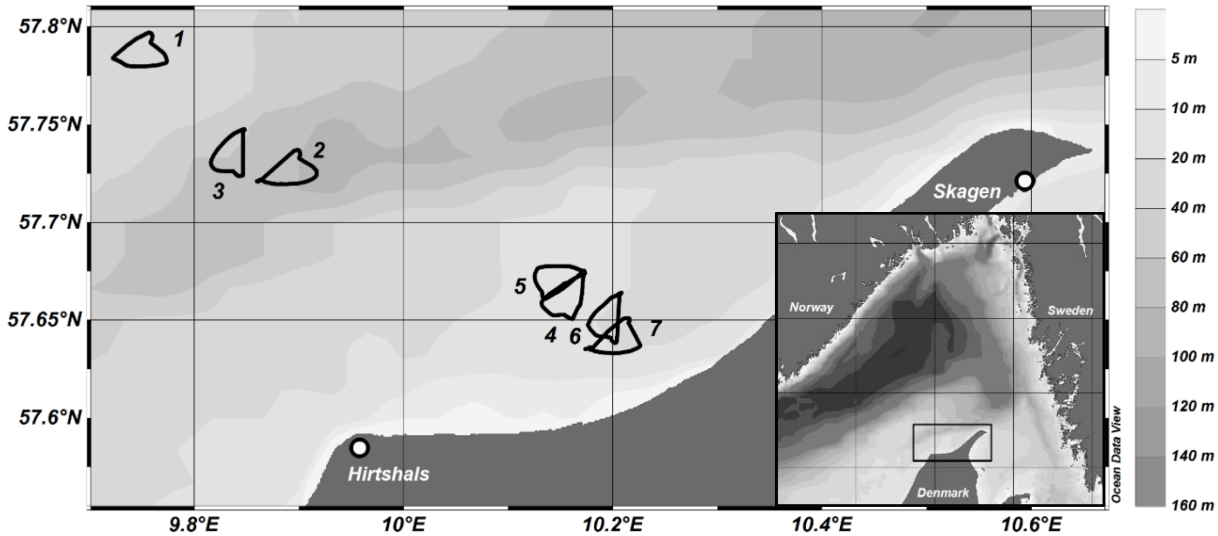

Figure 1. Area and vessel tracks for the seven hauls conducted on board the HG 35 Vendelbo in 2014.

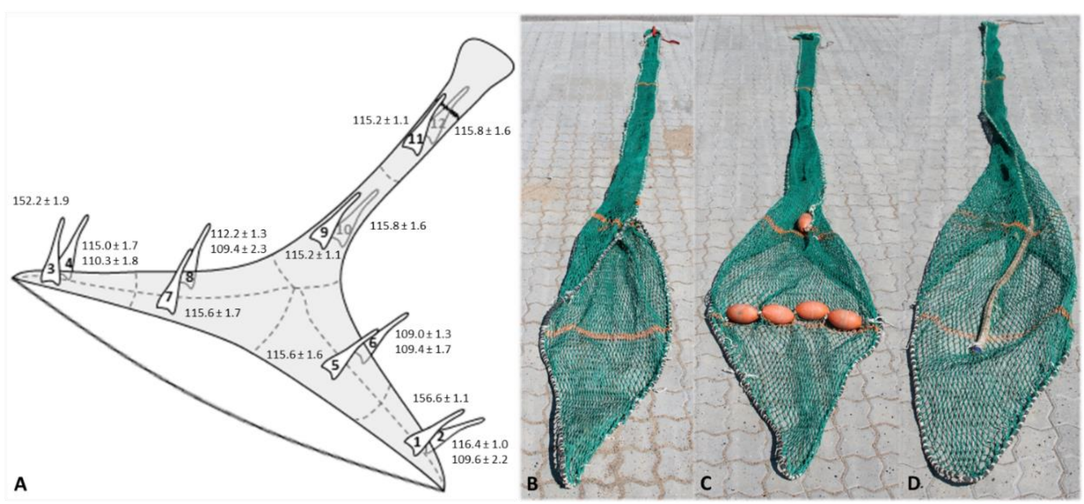

Figure 2. Collecting bags. A. Approximate locations, where bags were attached to seine net including mesh size in mm of the netting that was covered by the collecting bag (± standard deviation). B. Standard bag (1-8). C. Upper bag with additional floats (9+11). D. Lower bag with additional lead-filled rope (10+12).

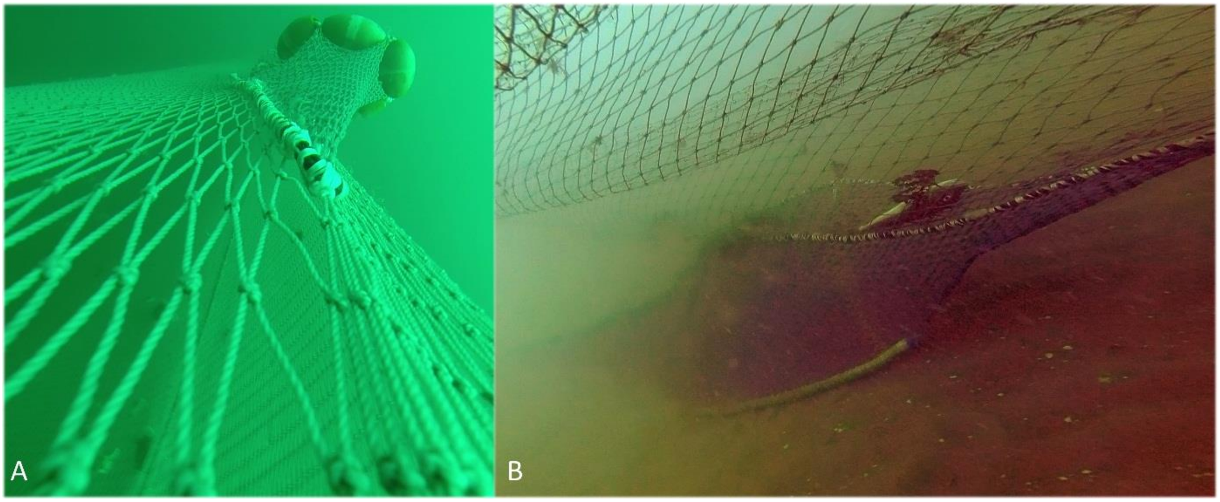

Figure 3. Examples of underwater observations, here collecting bags 9 (A; taken in final phase of haul 1) and 10 (B; taken in Haul 7 shortly before vessel returned to the anchor) showing that floats and lead rope functioned well in order to keep bags opened.

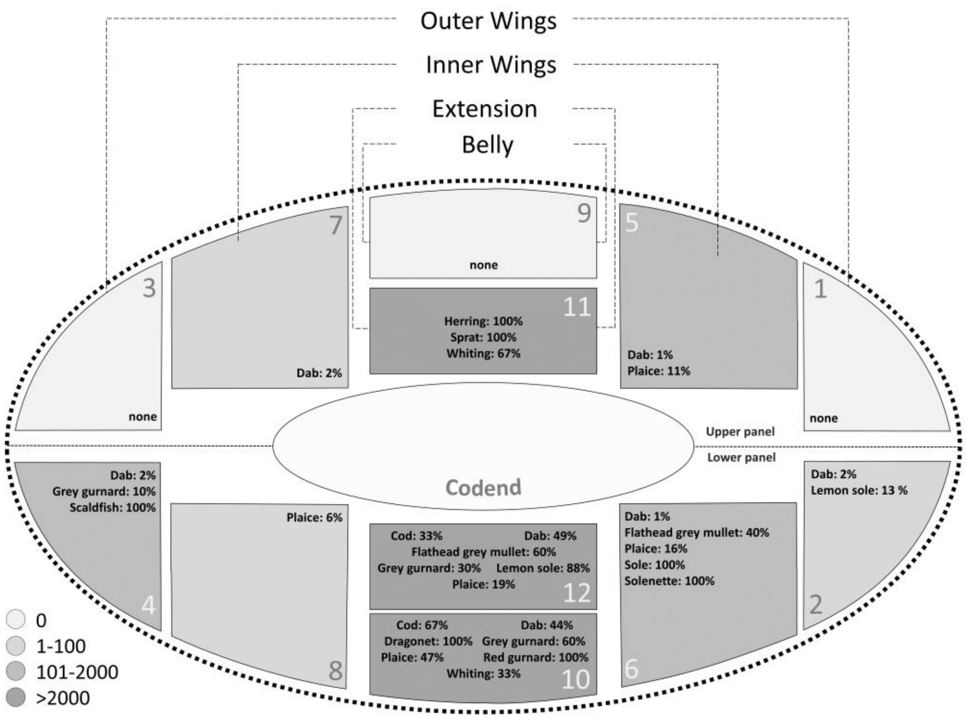

Figure 4. Raised individual numbers of fish species separated by gear part. Number in fields represents bag number, shade indicates absolute total number of individuals in the specific bag and percentage value indicates relative frequency of each species in all collecting bags.

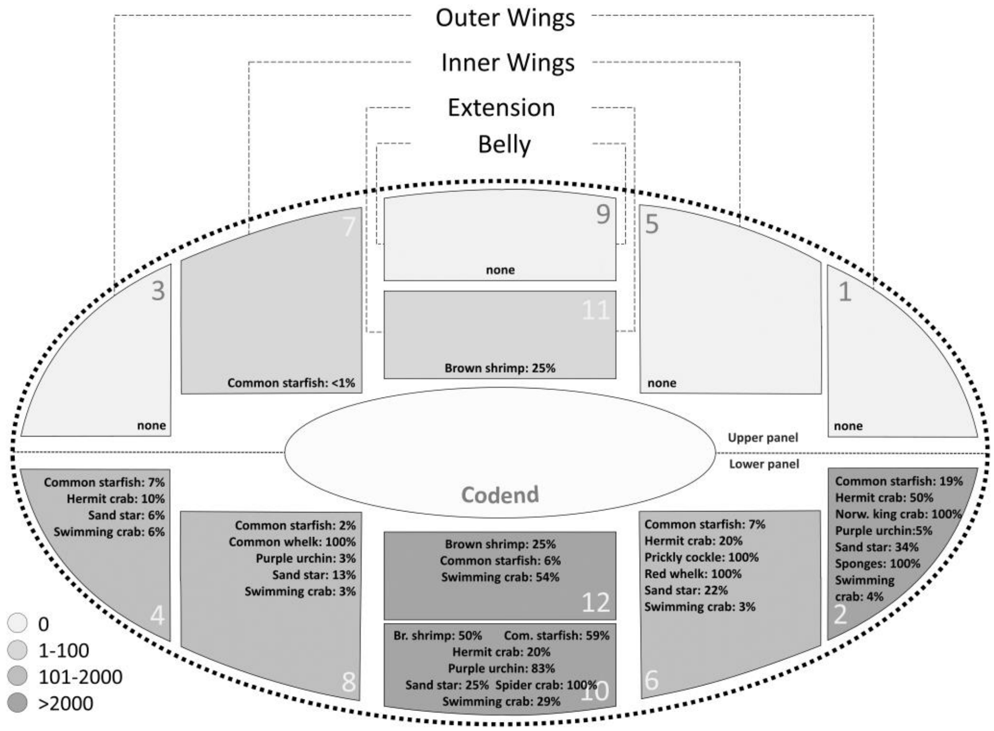

Figure 5. Raised individual numbers of invertebrate species separated by gear part. Number in fields represents bag number, shade indicates absolute total number of individuals in the specific bag and percentage value indicates relative frequency of each species in all collecting bags.

Tables

Table 1. Length key and damage key (modified from Veale *et al.* (2001); the higher the more damage) for invertebrate species, ordered by taxonomic class.

Class	Species	Length measurement	Damage index				
			1	2	3	4	5
Asteroidea	Common starfish (*Asterias rubens*)	maximum extent	no visible damage	- 1 arm	-2 arms	-3 to -4 arms	no arms
	Sand star (*Astropecten irregularis*)	maximum extent	no visible damage	- 1 arm	-2 arms	-3 to -4 arms	no arms
	Spiny starfish (*Marthasterias glacialis*)	maximum extent	no visible damage	- 1 arm	-2 arms	-3 to -4 arms	no arms
Malacostraca	Edible crab (*Cancer pagurus*)	carapace width	no visible damage	-1 to -2 legs	-3 to -4 legs	-5 or more legs	broken carapax
	Brown shrimp (*Crangon crangon*)	carapace length	no visible damage	-1 to -2 legs	-3 to -4 legs	-5 or more legs	broken carapax
	Sandy swimming crab (*Liocarcinus depurator*)	carapace width	no visible damage	-1 to -2 legs	-3 to -4 legs	-5 or more legs	broken carapax
	Norway king crab (*Lithodes maja*)	carapace length	no visible damage	-1 to -2 legs	-3 to -4 legs	-5 or more legs	broken carapax
	Common spider crab (*Macropodia rostrata*)	carapace length	no visible damage	-1 to -2 legs	-3 to -4 legs	-5 or more legs	broken carapax
	Hermit crabs (*Pagurus* spp.)	maximum shell extent	no visible damage	gentle	out of shell, intact	out of shell, not intact	broken carapax
Bivalvia	Prickly cockle (*Acanthocardia echinata*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	Horse mussel (*Modiolus modiolus*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	Queen scallop (*Aequipecten opercularis*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
Gastropoda	Common whelk (*Buccinum undatum*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	Red whelk (*Neptunea antiqua*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
Other	Purple heart urchin (*Spatangus purpureus*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	Sea mouse (*Aphrodite aculeata*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	European squid (*Loligo vulgaris*)	maximum extent	no visible damage	gentle	medium	strong	irreparabel
	Crevice brittlestar (*Ophiopholis aculeata*)	maximum extent	no visible damage	- 1 arm	-2 arms	-3 to -4 arms	no arms
	Sponges (*Porifera*)	maximum extent	-	-	no visible damage	medium	strong
	Sea anemones (*Actinaria* spp.)	maximum extent	-	-	no visible damage	medium	strong

Table 2. Haul overview. Duration describes time from setting anchor until gear is retrieved onboard. Depth is given for position where anchor was set and where the seine was deployed. Sea state after Wileman et al. (1996).

Haul	Date	Duration (min)	Covered area (km²)	Depth (m)		Sea state	Total catch (kg)	
				Anchor	Seine		Codend	Collecting bags
1	23.08.2014	145	3.44	32.9	34.7	5	576.4	0.5
2	26.08.2014	151	3.42	69.5	73.2	2	2172.4	0.5
3	26.08.2014	135	3.17	42.1	54.9	2	860.1	2.4
4	27.08.2014	166	3.52	15.2	15.2	3	135.2	1.0
5	27.08.2014	160	3.13	15.2	15.7	2	94.1	0.5
6	27.08.2014	131	2.60	18.3	12.8	1	260.7	0.6
7	28.08.2014	180	3.17	18.3	13.7	2	370.6	0.9

Table 3. Catch overview for fish species with number of individuals observed in respective bags (raised number, representing the expected escapee number of the whole gear part in brackets) and codend. Average length ± standard deviation is given combined for all upper bags, combined for all lower bags and for codend. Mean values that are not sharing a letter (a, b, c) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	Individual numbers (raised to gear part)													Average size ± SD (cm)	
	Collecting bags (%, the single bags represent of whole gear)												Codend		
	1 (3%)	2 (4%)	3 (3%)	4 (4%)	5 (3%)	6 (4%)	7 (3%)	8 (4%)	9 (14%)	10 (14%)	11 (15%)	12 (10%)		Bags (up)	Bags (low)
Brill	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-
Cod	-	-	-	-	-	-	-	-	-	1 (100)	-	1 (50)	104	-	10.0 ± 1.4 a
Common dragonet	-	-	-	-	-	-	-	-	-	3 (300)	-	-	0	-	17.0 ± 1.0
Dab	-	1 (50)	-	1 (50)	1 (20)	1 (33)	4 (57)	-	-	14 (1400)	-	31 (1550)	776	25.4 ± 2.7 b	12.8 ± 4.0 a
Flathead grey mullet	-	-	-	-	-	1 (33)	-	-	-	-	-	1 (50)	1	-	5.0 ± 0.0
Flounder	-	-	-	-	-	-	-	-	-	-	-	-	21	-	-
Grey gurnard	-	-	-	1 (50)	-	-	-	-	-	3 (300)	-	3 (150)	22	-	9.7 ± 3.2 a
Haddock	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Hake	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-
Herring	-	-	-	-	-	-	-	-	-	-	13 (1300)	-	0	11.0 ± 1.0	-
Lemon sole	-	1 (50)	-	-	-	-	-	-	-	-	-	7 (350)	8	-	14.6 ± 2.4 a
Lesser spotted dogfish	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Ling	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Long rough dab	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Mackerel	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Plaice	-	-	-	-	6 (120)	5 (167)	-	2 (67)	-	5 (500)	-	4 (200)	15188	22.0 ± 2.2 b	12.7 ± 4.3 a
Pogge	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Red gurnard	-	-	-	-	-	-	-	-	-	1 (100)	-	-	394	-	24.0 ± 0.0 a
Scaldfish	-	-	-	1 (50)	-	-	-	-	-	-	-	-	0	-	11.0 ± 0.0
Sculpins	-	-	-	-	-	-	-	-	-	-	-	-	4	-	-
Sole	-	-	-	-	-	1 (33)	-	-	-	-	-	-	1	-	15.0 ± 0.0
Solenette	-	-	-	-	-	1 (33)	-	-	-	-	-	-	0	-	3.0 ± 0.0

Sprat	-	-	-	-	-	-	-	-	-	-	6 (600)	-	0	9.4 ± 1.1	-
Turbot	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
Whiting	-	-	-	-	-	-	-	-	-	1 (100)	2 (200)	-	2	9.5 ± 0.7 a	12.0 ± 0.0 a
Witch flounder	-	-	-	-	-	-	-	-	-	-	-	-	8	-	-

Table 4. Catch overview for invertebrate species with number of individuals observed in respective bags (raised number, representing the expected escapee number of the whole gear part in brackets) and codend. Average length ± standard deviation is given combined for all upper bags, combined for all lower bags and for codend. Mean values that are not sharing a letter (a, b, c) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; α ≤ 0.05).

Species	Individual numbers (raised to gear part)													Average size ± SD (cm)	
	Collecting bags (%, the single bags represent of whole gear)												Codend		
	1 (3%)	2 (4%)	3 (3%)	4 (4%)	5 (3%)	6 (4%)	7 (3%)	8 (4%)	9 (14%)	10 (14%)	11 (15%)	12 (10%)		Bags (up)	Bags (low)
Brown shrimp	-	-	-	-	-	-	-	-	-	2 (200)	1 (100)	2 (100)	0	1.1 ± 0.0 b	0.8 ± 0.1 a
Common spider crab	-	-	-	-	-	-	-	-	-	1 (100)	-	-	0	-	2.0 ± 0.0
Common starfish	-	13 (650)	-	5 (250)	-	7 (233)	1 (14)	2 (67)	-	20 (2000)	-	4 (200)	111	17.9 ± 0.0 b	10.1 ± 2.8 a
Common whelk	-	-	-	-	-	-	-	6 (200)	-	-	-	-	1	-	6.1 ± 0.4 a
Crevice brittlestar	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Edible crab	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
European squid	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
Hermit crabs	-	5 (250)	-	1 (50)	-	3 (100)	-	-	-	1 (100)	-	-	97	-	5.1 ± 2.3 a
Horse mussel	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-
Norway king crab	-	1 (50)	-	-	-	-	-	-	-	-	-	-	0	-	0.8 ± 0.0
Prickly cockle	-	-	-	-	-	1 (33)	-	-	-	-	-	-	0	-	5.3 ± 0.0
Purple heart urchin	-	1 (50)	-	-	-	-	-	1 (33)	-	10 (1000)	-	-	0	-	1.1 ± 0.7
Queen scallop	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-
Red whelk	-	-	-	-	-	5 (167)	-	-	-	-	-	-	16	-	6.6 ± 0.5 a
Sand star	-	22 (1100)	-	4 (200)	-	21 (700)	-	13 (433)	-	8 (800)	-	-	44	-	7.0 ± 1.1 a
Sandy swimming crab	-	4 (200)	-	6 (300)	-	5 (167)	-	4 (133)	-	14 (1400)	-	52 (2600)	101	-	3.0 ± 0.9 a
Sea anemones	-	-	-	-	-	-	-	-	-	-	-	-	6	-	-
Sea mouse	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-

Spiny starfish	-	-	-	-	-	-	-	-	-	-	-	-	25	-	-
Sponges	-	1 (50)	-	-	-	-	-	-	-	-	-	-	32	-	2.9 ± 0.0 a

Table 5. Damage levels for invertebrate species that were observed in at least two parts following levels, explained in Table 1, separated by gear part. Mean values that are not sharing a letter (a, b) are significantly different (two-way ANOVA and post-hoc Tukey-HSD test; $\alpha \leq 0.05$).

Species	Compartment				
	Inner wings	Outer wings	Belly	Extension	Codend
Common starfish	1.33 a	1.65 ab	1.40 a	3.25 b	1.92 ab
Sand star	1.27 a	1.82 a	1.88 ab	-	2.91 ab
Common whelk	-	1.00 a	-	-	1.00 a
Brown shrimp	-	-	1.00 a	1.00 a	-
Sandy swimming crab	1.1 a	1.00 a	1.36 a	1.56 a	1.64 a
Red whelk	-	1.00 a	-	-	1.00 a
Hermit crabs	1.33 a	1.00 a	1.00 a	-	1.21 a
Sponges	3.00 a	-	-	-	3.00 a
Purple heart urchin	1.00 a	1.00 a	1.00 a	-	-

Supplementary material

Table S1. Fish species observed within the study.

Species	Scientific name
Brill	*Scophthalmus rhombus*
Cod	*Gadus morhua*
Common dab	*Limanda limanda*
Common dragonet	*Callionymus lyra*
Flathead grey mullet	*Mugil cephalus*
Flounder	*Platichthys flesus*
Grey gurnard	*Eutrigla gurnardus*
Haddock	*Melanogrammus aeglefinus*
Hake	*Merluccius merluccius*
Herring	*Clupea harengus*
Lemon sole	*Microstomus kitt*
Lesser spotted dogfish	*Scyliorhinus canicula*
Ling	*Molva molva*
Long rough dab	*Hippoglossoides platessoides*
Mackerel	*Scomber scombrus*
Plaice	*Pleuronectes platessa*
Pogge	*Agonus cataphractus*
Red gurnard	*Chelidonichthys lucernus*
Scaldfish	*Arnoglossus laterna*
Sculpins	*Myoxocephalus spp.*
Sole	*Solea solea*
Solenette	*Buglossidium luteum*
Sprat	*Sprattus sprattus*
Turbot	*Psetta maxima*
Whiting	*Merlangius merlangus*
Witch flounder	*Glyptocephalus cynoglossus*